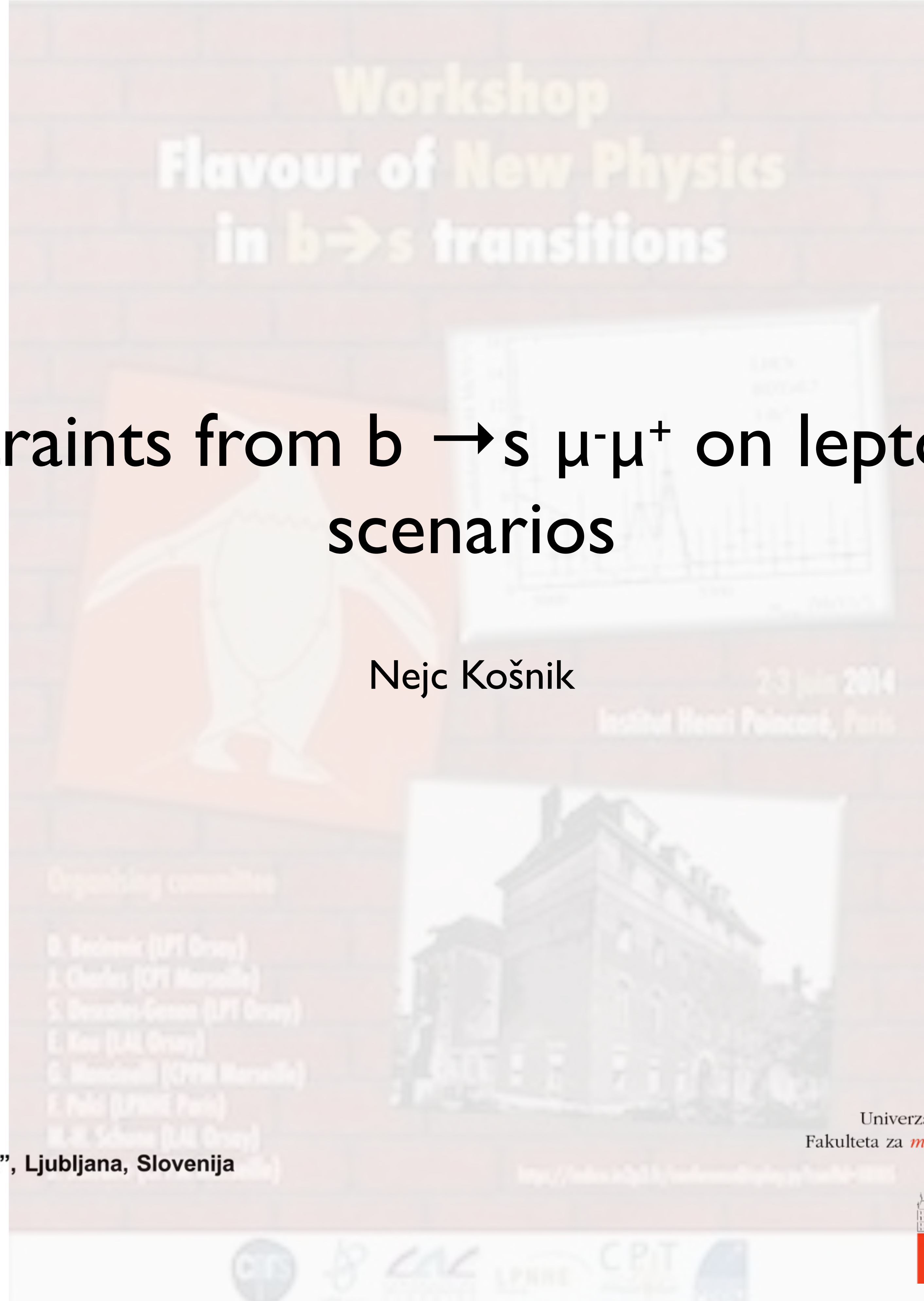

Constraints from b →s $\mu^-\mu^+$ on leptoquark scenarios

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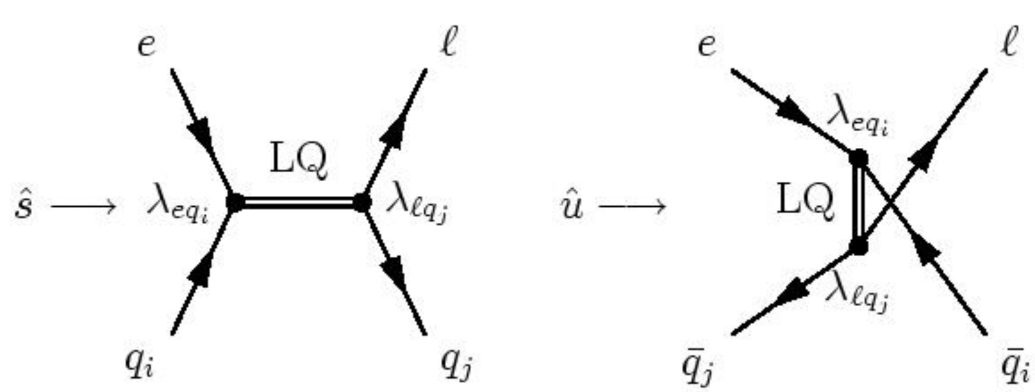
Leptoquarks. What?

- Boson color triplets, talking to a lepton and a quark
- Natural in theories with mixed lepton/quark multiplets

  Grand unified theories, Pati-Salam unification, composite scenarios

- vector or scalar (role of gauge boson or Higgs in GUT)
- fermion number F = 2 or F = 0 (F = 3B+L)



[H1 Collaboration]

Leptoquarks. Pros and cons.

Their presence generates, at tree level:

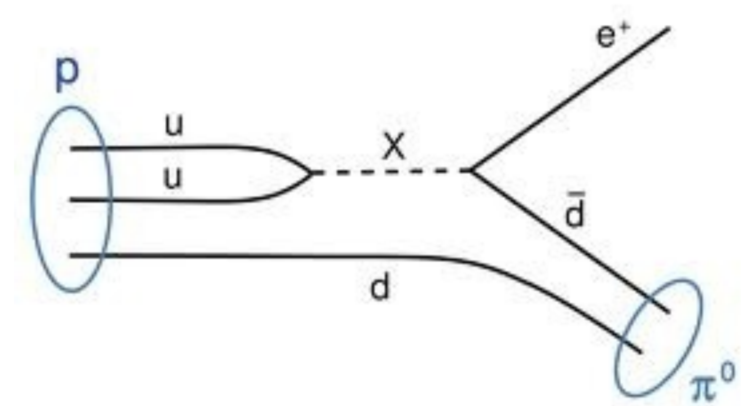
- quark flavour violation
- neutral current processes with quarks
- lepton flavor violation

If LQ endowed with di-quark couplings, then state has ill-defined B and L numbers.

Their mass should be of the order M_{GUT} due to proton decay.

$$\tau_p > 10^{34}\,\mathrm{yr}$$

[Super-Kamiokande(1996-2008)]



Effective renormalizable framework

Above the weak scale complement the Standard model with (super)renormalizable terms

$$\mathcal{L} = \mathcal{L}_{\rm SM} + |D_\mu \Delta|^2 - {m_\Delta}^2 |\Delta|^2 + Y_{ij} \Delta \bar{f}_i f_j$$

Δ = scalar/vector state with well defined quantum numbers, e.g., (3,2,1/6)

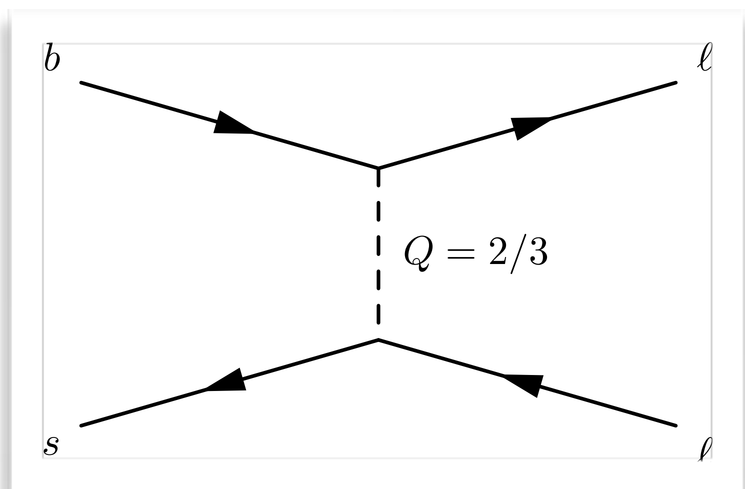
Remarks:

- add single scalar/vector leptoquark at a time
- UV symmetry hidden, Lagrangian invariant under the SM gauge group
- Mass of the state is not proportional to VEV of the SM Higgs
- Fermion couplings (Yukawas) and LQ mass are new free parameters
- Renormalizable theory => UV independent => "model independent" framework.

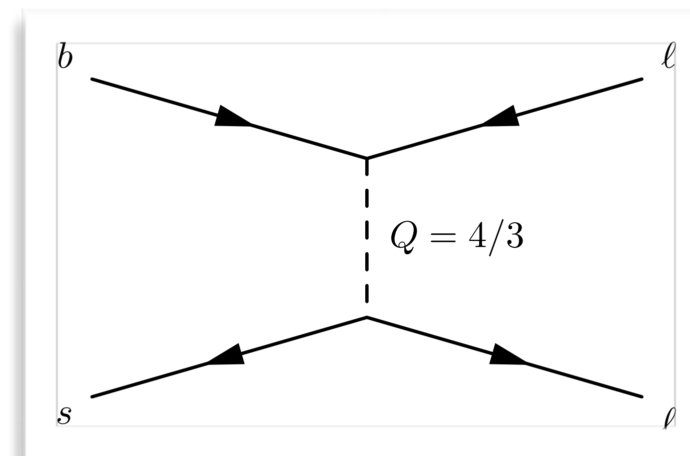
In other words … a perfectly viable scenario.

Leptoquarks in b$\underline{s}$ → μ⁺μ⁻

Build appropriate LQ currents out of SM fermions:



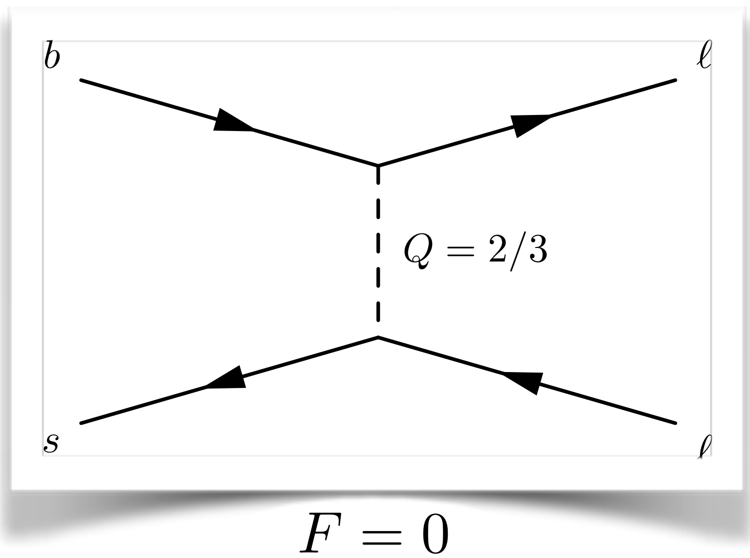
$F = 0$



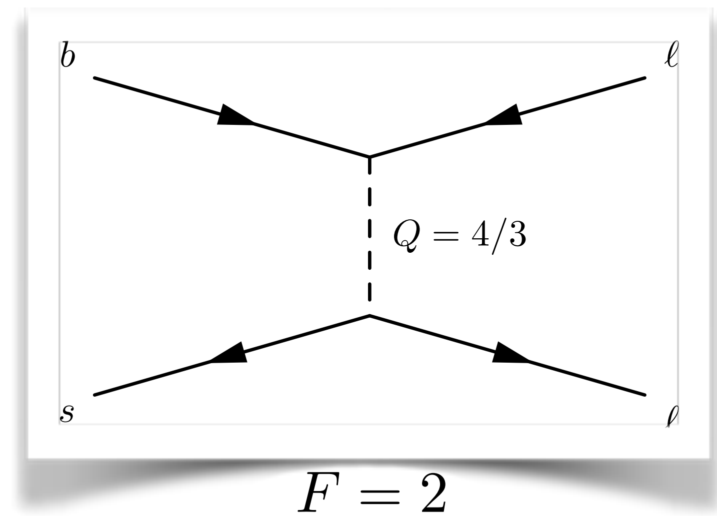
$F = 2$

Leptoquarks in b$\underline{s}$ $\to \mu^+\mu^-$

Build appropriate LQ currents out of SM fermions:



$F = 0$



$F = 2$

$\bar{Q}\ell_R$

$\bar{d}_R L$

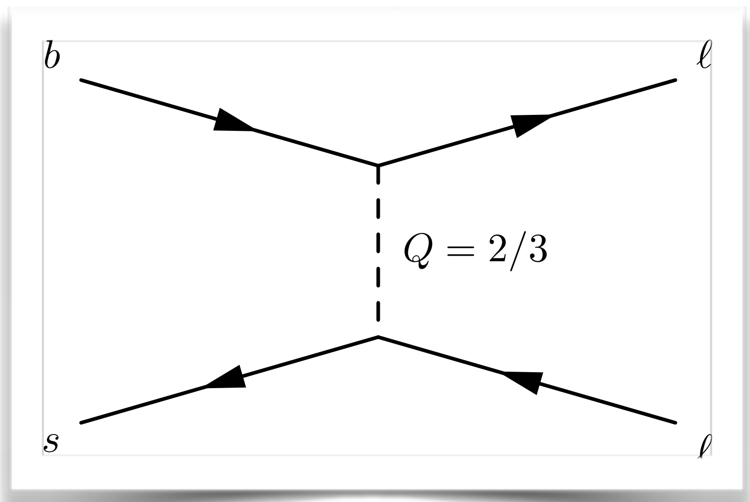
scalars

$\overline{Q^C} i\tau_2 \boldsymbol{\tau} \quad L$

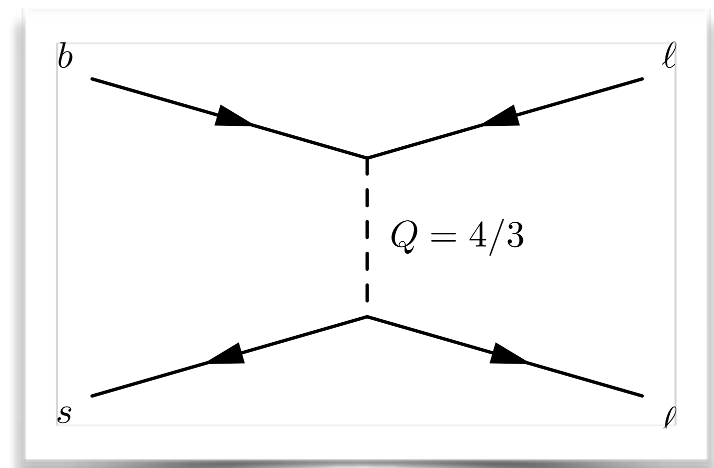
$\overline{d_R^C}\ell_R$

Leptoquarks in b$\underline{s}$ → μ⁺μ⁻

Build appropriate LQ currents out of SM fermions:



$F = 0$

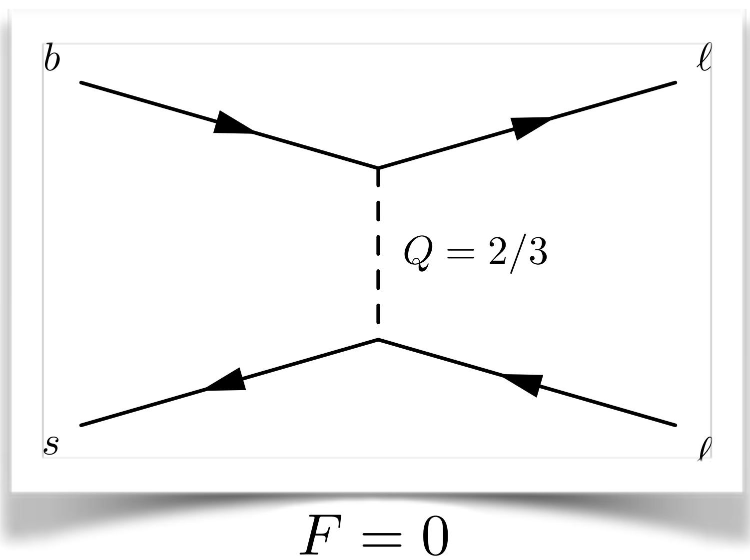


$F = 2$

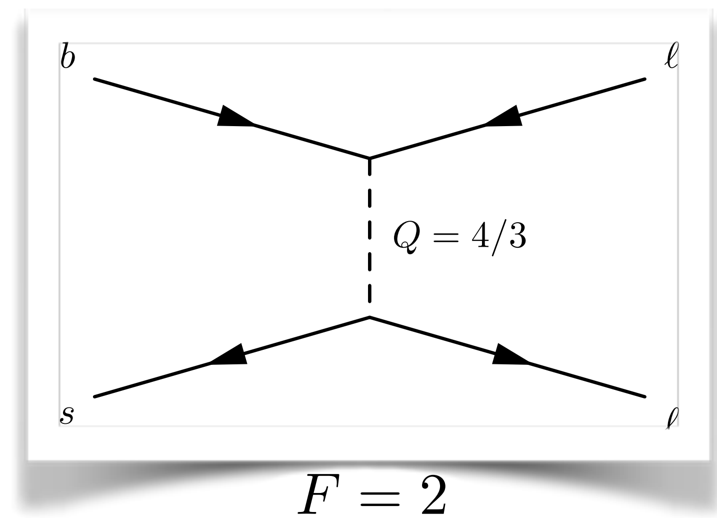
F = 0		F = 2
$\bar{Q}\ell_R$ $\bar{d}_R L$	scalars	$\overline{Q^C} i\tau_2 \boldsymbol{\tau} \quad L$ $\overline{d_R^C}\ell_R$
$\bar{d}_R\gamma^\mu\ell_R$ $\bar{Q}\boldsymbol{\tau}\gamma^\mu L$	vectors	$\overline{Q^C}\, i\tau_2\gamma^\mu\ell_R$

Leptoquarks in b$\underline{s}$ → μ⁺μ⁻

Build appropriate LQ currents out of SM fermions:



$F = 0$



$F = 2$

scalars

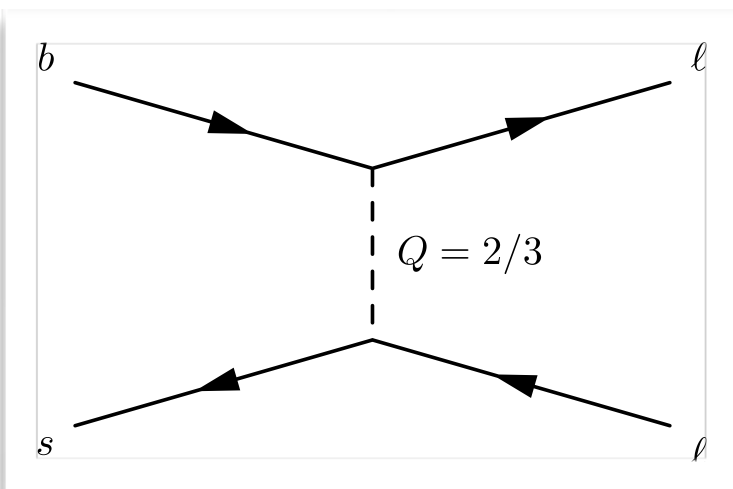
$\bar{Q}\ell_R$	$(\bar{3}, 2, -7/6)$	$\overline{Q^C} i\tau_2 \boldsymbol{\tau} \cdot L$	$(3, \bar{3})_{-1/3}$
$\bar{d}_R L$	$(\bar{3}, 2, -1/6)$	$\overline{d_R^C}\ell_R$	$(3, 1)_{-4/3}$

vectors

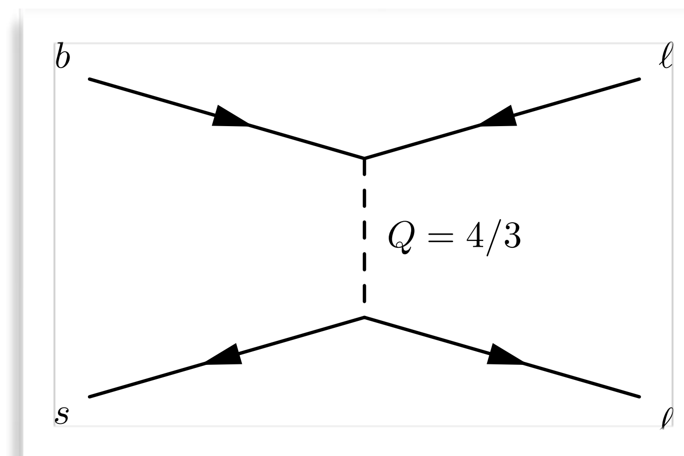
$\bar{d}_R\gamma^\mu\ell_R$	$(\bar{3}, 1, -2/3)$	$\overline{Q^C}\, i\tau_2\gamma^\mu\ell_R$	$(3, 2, -5/6)$
$\bar{Q}\boldsymbol{\tau}\gamma^\mu L$	$(\bar{3}, 3, -2/3)$		

Leptoquarks in b$\underline{s}$ →μ⁺μ⁻

Build appropriate LQ currents out of SM fermions:



$F = 0$



$F = 2$

scalars Δ

$\Delta^{(7/6)}\ \bar{Q}\ell_R \quad (\bar{3}, 2, -7/6)$

$\Delta^{(1/6)}\ \bar{d}_R L \quad (\bar{3}, 2, -1/6)$

$\Delta^{(1/3)}\ \overline{Q^C} i\tau_2 \boldsymbol{\tau}\cdot L \quad (3, \bar{3})_{-1/3}$

$\Delta^{(4/3)}\ \overline{d_R^C}\ell_R \quad (3, 1)_{-4/3}$

vectors V

$V^{(1)}\ \bar{d}_R\gamma^\mu\ell_R \quad (\bar{3}, 1, -2/3)$

$V^{(3)}\ \bar{Q}\boldsymbol{\tau}\gamma^\mu L \quad (\bar{3}, 3, -2/3)$

$V^{(2)}\ \overline{Q^C}\ i\tau_2\gamma^\mu\ell_R \quad (3, 2, -5/6)$

Leptoquarks in b$\underline{s}$ →μ⁺μ⁻

In the effective Hamiltonian language:

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}}\lambda_t\Big[\sum_{i=1}^{6} C_i(\mu)\mathcal{O}_i(\mu) + \sum_{i=7,8,9,10,P,S}(C_i(\mu)\mathcal{O}_i(\mu) + C_i'(\mu)\mathcal{O}_i'(\mu)) + C_T\mathcal{O}_T + C_{T5}\mathcal{O}_{T5}\Big]$$

$$\mathcal{O}_9 = \frac{e^2}{g^2}(\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu\ell)\,, \qquad \mathcal{O}_S = \frac{e^2}{16\pi^2}(\bar{s}P_R b)(\bar{\ell}\ell)\,, \qquad \mathcal{O}_T = \frac{e^2}{16\pi^2}(\bar{s}\sigma^{\mu\nu}b)(\bar{\ell}\sigma_{\mu\nu}\ell)\,,$$

$$\mathcal{O}_{10} = \frac{e^2}{g^2}(\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu\gamma_5\ell)\,, \qquad \mathcal{O}_P = \frac{e^2}{16\pi^2}(\bar{s}P_R b)(\bar{\ell}\gamma_5\ell)\,. \qquad \mathcal{O}_{T5} = \frac{e^2}{16\pi^2}(\bar{s}\sigma^{\mu\nu}b)(\bar{\ell}\sigma_{\mu\nu}\gamma_5\ell)\,.$$

scalars Δ

$\Delta^{(7/6)}$	$\bar{Q}\ell_R$	$(\bar{3},2,-7/6)$	$\Delta^{(1/3)}$	$\overline{Q^C}i\tau_2\boldsymbol{\tau}\cdot L$	$(3,\bar{3})_{-1/3}$
$\Delta^{(1/6)}$	$\bar{d}_R L$	$(\bar{3},2,-1/6)$	$\Delta^{(4/3)}$	$\overline{d_R^C}\ell_R$	$(3,1)_{-4/3}$

vectors V

$V^{(1)}$	$\bar{d}_R\gamma^\mu\ell_R$	$(\bar{3},1,-2/3)$	$V^{(2)}$	$\overline{Q^C}\,i\tau_2\gamma^\mu\ell_R$	$(3,2,-5/6)$
$V^{(3)}$	$\bar{Q}\boldsymbol{\tau}\gamma^\mu L$	$(\bar{3},3,-2/3)$			

Leptoquarks in b$\underline{\text{s}}$ → $\mu^+\mu^-$

In the effective Hamiltonian language:

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}}\lambda_t\Big[\sum_{i=1}^{6} C_i(\mu)\mathcal{O}_i(\mu) + \sum_{i=7,8,9,10,P,S}(C_i(\mu)\mathcal{O}_i(\mu) + C'_i(\mu)\mathcal{O}'_i(\mu)) + C_T\mathcal{O}_T + C_{T5}\mathcal{O}_{T5}\Big]$$

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scalars Δ

$\Delta^{(7/6)}$	$\bar{Q}\ell_R$	$(\bar{3}, 2, -7/6)$
$\Delta^{(1/6)}$	$\bar{d}_R L$	$(\bar{3}, 2, -1/6)$
$\Delta^{(1/3)}$	$\overline{Q^C}i\tau_2\boldsymbol{\tau}\cdot L$	$(3, \bar{3})_{-1/3}$
$\Delta^{(4/3)}$	$\overline{d^C_R}\ell_R$	$(3, 1)_{-4/3}$

vectors V

$V^{(1)}$	$\bar{d}_R\gamma^\mu\ell_R$	$(\bar{3}, 1, -2/3)$
$V^{(3)}$	$\bar{Q}\boldsymbol{\tau}\gamma^\mu L$	$(\bar{3}, 3, -2/3)$
$V^{(2)}$	$\overline{Q^C}\, i\tau_2\gamma^\mu\ell_R$	$(3, 2, -5/6)$

Leptoquarks in bs → $\mu^+\mu^-$

In the effective Hamiltonian language:

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}}\lambda_t\Big[\sum_{i=1}^{6} C_i(\mu)\mathcal{O}_i(\mu) + \sum_{i=7,8,9,10,P,S}(C_i(\mu)\mathcal{O}_i(\mu) + C_i'(\mu)\mathcal{O}_i'(\mu)) + C_T\mathcal{O}_T + C_{T5}\mathcal{O}_{T5}\Big]$$

$$\mathcal{O}_9 = \frac{e^2}{g^2}(\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu\ell)\,,\qquad \mathcal{O}_S = \frac{e^2}{16\pi^2}(\bar{s}P_R b)(\bar{\ell}\ell)\,,\qquad \mathcal{O}_T = \frac{e^2}{16\pi^2}(\bar{s}\sigma^{\mu\nu}b)(\bar{\ell}\sigma_{\mu\nu}\ell)\,,$$

$$\mathcal{O}_{10} = \frac{e^2}{g^2}(\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu\gamma_5\ell)\,,\qquad \mathcal{O}_P = \frac{e^2}{16\pi^2}(\bar{s}P_R b)(\bar{\ell}\gamma_5\ell)\,.\qquad \mathcal{O}_{T5} = \frac{e^2}{16\pi^2}(\bar{s}\sigma^{\mu\nu}b)(\bar{\ell}\sigma_{\mu\nu}\gamma_5\ell)\,.$$

$\Delta^{(7/6)}$ $\bar{Q}\ell_R$ $(\bar{3}, 2, -7/6)$ **scalar**

$$\mathcal{L}^{(7/6)} = g_R\,\overline{Q}\Delta^{(7/6)}\ell_R$$

→

$$C_9 = C_{10} = \frac{-\pi}{2\sqrt{2}G_F\lambda_t\alpha}\frac{(g_R)_{s\ell}(g_R)^*_{b\ell}}{M^2_{\Delta^{(7/6)}}}\,.$$

(defined in the down-quark mass basis)

Leptoquarks in b$\underline{s}$ →μ⁺μ⁻

In the effective Hamiltonian language:

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}}\lambda_t\Big[\sum_{i=1}^{6} C_i(\mu)\mathcal{O}_i(\mu) + \sum_{i=7,8,9,10,P,S}(C_i(\mu)\mathcal{O}_i(\mu) + C_i'(\mu)\mathcal{O}_i'(\mu)) + C_T\mathcal{O}_T + C_{T5}\mathcal{O}_{T5}\Big]$$

$$\mathcal{O}_9 = \frac{e^2}{g^2}(\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu\ell)\,, \qquad \mathcal{O}_S = \frac{e^2}{16\pi^2}(\bar{s}P_R b)(\bar{\ell}\ell)\,, \qquad \mathcal{O}_T = \frac{e^2}{16\pi^2}(\bar{s}\sigma^{\mu\nu}b)(\bar{\ell}\sigma_{\mu\nu}\ell)\,,$$

$$\mathcal{O}_{10} = \frac{e^2}{g^2}(\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu\gamma_5\ell)\,, \qquad \mathcal{O}_P = \frac{e^2}{16\pi^2}(\bar{s}P_R b)(\bar{\ell}\gamma_5\ell)\,. \qquad \mathcal{O}_{T5} = \frac{e^2}{16\pi^2}(\bar{s}\sigma^{\mu\nu}b)(\bar{\ell}\sigma_{\mu\nu}\gamma_5\ell)\,.$$

$\Delta^{(7/6)}$ $\bar{Q}\ell_R$ $(\bar{3}, 2, -7/6)$ scalar

$$\mathcal{L}^{(7/6)} = g_R\,\overline{Q}\Delta^{(7/6)}\ell_R$$

LQs live in the Fierzed basis:
scalar exchange in the t-channel
⇒ (axial)vector operators

$$C_9 = C_{10} = \frac{-\pi}{2\sqrt{2}G_F\lambda_t\alpha}\,\frac{(g_R)_{s\ell}(g_R)^*_{b\ell}}{M^2_{\Delta^{(7/6)}}}\,.$$

(defined in the down-quark mass basis)

Leptoquarks in $b\underline{s} \to \mu^+\mu^-$

In the effective Hamiltonian language:

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}}\lambda_t\Big[\sum_{i=1}^{6} C_i(\mu)\mathcal{O}_i(\mu) + \sum_{i=7,8,9,10,P,S}(C_i(\mu)\mathcal{O}_i(\mu) + C_i'(\mu)\mathcal{O}_i'(\mu)) + C_T\mathcal{O}_T + C_{T5}\mathcal{O}_{T5}\Big]$$

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scalars Δ

$\Delta^{(7/6)}$	$\bar{Q}\ell_R$	$(\bar{3},2,-7/6)$	$\Delta^{(1/3)}$	$\overline{Q^C}i\tau_2\boldsymbol{\tau}\cdot L$	$(3,\bar{3})_{-1/3}$
$\Delta^{(1/6)}$	$\bar{d}_R L$	$(\bar{3},2,-1/6)$	$\Delta^{(4/3)}$	$\overline{d_R^C}\ell_R$	$(3,1)_{-4/3}$

vectors V

$V^{(1)}$	$\bar{d}_R\gamma^\mu\ell_R$	$(\bar{3},1,-2/3)$	$V^{(2)}$	$\overline{Q^C}\,i\tau_2\gamma^\mu\ell_R$	$(3,2,-5/6)$
$V^{(3)}$	$\bar{Q}\boldsymbol{\tau}\gamma^\mu L$	$(\bar{3},3,-2/3)$			

Leptoquarks in bs → μ⁺μ⁻

In the effective Hamiltonian language:

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}}\lambda_t\Big[\sum_{i=1}^{6} C_i(\mu)\mathcal{O}_i(\mu) + \sum_{i=7,8,9,10,P,S}(C_i(\mu)\mathcal{O}_i(\mu) + C_i'(\mu)\mathcal{O}_i'(\mu)) + C_T\mathcal{O}_T + C_{T5}\mathcal{O}_{T5}\Big]$$

$$\mathcal{O}_9 = \frac{e^2}{g^2}(\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu\ell)\,, \qquad \mathcal{O}_S = \frac{e^2}{16\pi^2}(\bar{s}P_R b)(\bar{\ell}\ell)\,, \qquad \mathcal{O}_T = \frac{e^2}{16\pi^2}(\bar{s}\sigma^{\mu\nu}b)(\bar{\ell}\sigma_{\mu\nu}\ell)\,,$$

$$\mathcal{O}_{10} = \frac{e^2}{g^2}(\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu\gamma_5\ell)\,, \qquad \mathcal{O}_P = \frac{e^2}{16\pi^2}(\bar{s}P_R b)(\bar{\ell}\gamma_5\ell)\,. \qquad \mathcal{O}_{T5} = \frac{e^2}{16\pi^2}(\bar{s}\sigma^{\mu\nu}b)(\bar{\ell}\sigma_{\mu\nu}\gamma_5\ell)\,.$$

$$\mathcal{L}^{(1)} = \left(g_L\,\overline{Q}\gamma^\mu L + g_R\,\overline{d_R}\gamma^\mu\ell_R\right)\, V_\mu^{(1)}$$

vector

$V^{(1)}$ $\bar{d}_R\gamma^\mu\ell_R$ $(\bar{3}, 1, -2/3)$

$$C_9 = -C_{10} = \frac{\pi}{\sqrt{2}G_F\lambda_t\alpha}\frac{(g_L)_{s\ell}(g_L)^*_{b\ell}}{M^2_{V^{(1)}}}$$

$$C_9' = C_{10}' = \frac{\pi}{\sqrt{2}G_F\lambda_t\alpha}\frac{(g_R)_{s\ell}(g_R)^*_{b\ell}}{M^2_{V^{(1)}}}$$

$$-C_P = C_S = \frac{\sqrt{2}\pi}{G_F\lambda_t\alpha}\frac{(g_L)_{s\ell}(g_R)^*_{b\ell}}{M^2_{V^{(1)}}}$$

$$C_P' = C_S' = \frac{\sqrt{2}\pi}{G_F\lambda_t\alpha}\frac{(g_R)_{s\ell}(g_L)^*_{b\ell}}{M^2_{V^{(1)}}}$$

Leptoquarks in b<u>s</u> →μ⁺μ⁻

In the effective Hamiltonian language:

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$$\mathcal{O}_9 = \frac{e^2}{g^2}(\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu\ell)\,, \qquad \mathcal{O}_S = \frac{e^2}{16\pi^2}(\bar{s}P_R b)(\bar{\ell}\ell)\,, \qquad \mathcal{O}_T = \frac{e^2}{16\pi^2}(\bar{s}\sigma^{\mu\nu}b)(\bar{\ell}\sigma_{\mu\nu}\ell)\,,$$

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$$\mathcal{L}^{(1)} = \left(g_L\,\overline{Q}\gamma^\mu L + g_R\,\overline{d_R}\gamma^\mu\ell_R\right) V_\mu^{(1)}$$

vector

$V^{(1)}\;\bar{d}_R\gamma^\mu\ell_R \qquad (\bar{3}, 1, -2/3)$

$$C_9 = -C_{10} = \frac{\pi}{\sqrt{2}G_F\lambda_t\alpha}\frac{(g_L)_{s\ell}(g_L)^*_{b\ell}}{M^2_{V^{(1)}}}$$

$$C'_9 = C'_{10} = \frac{\pi}{\sqrt{2}G_F\lambda_t\alpha}\frac{(g_R)_{s\ell}(g_R)^*_{b\ell}}{M^2_{V^{(1)}}}$$

$$-C_P = C_S = \frac{\sqrt{2}\pi}{G_F\lambda_t\alpha}\frac{(g_L)_{s\ell}(g_R)^*_{b\ell}}{M^2_{V^{(1)}}}$$

$$C'_P = C'_S = \frac{\sqrt{2}\pi}{G_F\lambda_t\alpha}\frac{(g_R)_{s\ell}(g_L)^*_{b\ell}}{M^2_{V^{(1)}}}$$

Nonchiral LQ,
(pseudo)scalars possible

Leptoquarks in $b\underline{s} \to \mu^+\mu^-$

Summary

S	LQ	BNC	$\mathcal{O}_9$	$\mathcal{O}_{10}$	$\mathcal{O}_S$	$\mathcal{O}_P$	$\mathcal{O}'_9$	$\mathcal{O}'_{10}$	$\mathcal{O}'_S$	$\mathcal{O}'_P$
0	$\Delta^{(7/6)}$	✓	C_{10}	C_{10}						
	$\Delta^{(1/6)}$	✓					$-C'_{10}$	C'_{10}		
	$\Delta^{(4/3)}$						C'_{10}	C'_{10}		
	$\Delta^{(1/3)}$		$-C_{10}$	C_{10}						
1	$V^{(3)}$	✓	$-C_{10}$	C_{10}						
	$V^{(1)}$		$-C_{10}$	C_{10}	C_S	$-C_S$	C'_{10}	C'_{10}	C'_S	C'_S
	$V^{(2)}$		C_{10}	C_{10}	C_S	C_S	$-C'_{10}$	C'_{10}	C'_S	$-C'_S$

Free (complex) parameters

General framework for a single LQ:

$$\begin{pmatrix} C_{10} \\ C'_{10} \\ C_P \\ C'_P \end{pmatrix} = \pm \begin{pmatrix} C_9 \\ -C'_9 \\ C_S \\ -C'_S \end{pmatrix}$$

$$4C_{10}C'_{10} = -C_S C'_S$$

at most 3 complex DOFs

Scalar leptoquarks in $b\bar{s} \to \mu^+\mu^-$

Scalars

S	LQ	BNC	$\mathcal{O}_9$	$\mathcal{O}_{10}$	$\mathcal{O}_S$	$\mathcal{O}_P$	$\mathcal{O}'_9$	$\mathcal{O}'_{10}$	$\mathcal{O}'_S$	$\mathcal{O}'_P$
0	$\Delta^{(7/6)}$	✓	C_{10}	C_{10}						
	$\Delta^{(1/6)}$	✓					$-C'_{10}$	C'_{10}		
	$\Delta^{(4/3)}$						C'_{10}	C'_{10}		
	$\Delta^{(1/3)}$		$-C_{10}$	C_{10}						

General framework for a single scalar LQ

$C_9 = \pm C_{10}$ or $C'_9 = \pm C'_{10}$

1 complex DOF

Scalar leptoquarks in $b\underline{s} \to \mu^+\mu^-$

Scalars

S	LQ	BNC	$\mathcal{O}_9$	$\mathcal{O}_{10}$	$\mathcal{O}_S$	$\mathcal{O}_P$	$\mathcal{O}'_9$	$\mathcal{O}'_{10}$	$\mathcal{O}'_S$	$\mathcal{O}'_P$
0	$\Delta^{(7/6)}$	✓	C_{10}	C_{10}						
	$\Delta^{(1/6)}$	✓					$-C'_{10}$	C'_{10}		
	$\Delta^{(4/3)}$						C'_{10}	C'_{10}		
	$\Delta^{(1/3)}$		$-C_{10}$	C_{10}						

General framework for a single scalar LQ

$C_9 = \pm C_{10}$ or $C'_9 = \pm C'_{10}$

1 complex DOF

Constrain above 4 scenarios in $B_s \to \mu\mu$, $B \to K\mu\mu$, $B \to X_s\mu\mu$!

Observables

$B_s \to \mu\mu$

$$\mathrm{Br}\left(B_s \to \ell^+\ell^-\right)^{\mathrm{BSM}} = \tau_{B_s} f_{B_s}^2 m_{B_s}^3 \frac{G_F^2\alpha^2}{64\pi^3} |V_{tb}V_{ts}^*|^2 \beta_\ell(m_{B_s}^2) \left[\frac{m_{B_s}^2}{m_b^2} \left|C_S - C_S'\right|^2 \left(1 - \frac{4m_\ell^2}{m_{B_s}^2}\right) + \left|\frac{m_{B_s}}{m_b}(C_P - C_P') + 2\frac{m_\ell}{m_{B_s}}(C_{10} - C_{10}')\right|^2 \right],$$

$$\mathrm{Br}^{\mathrm{BSM}}(1 + \mathcal{A}_{\Delta\Gamma} y_s)/(1 - y_s^2) = \mathrm{Br}^{\mathrm{exp}}$$

[ETM, HPQCD, RBC/UKQCD, FNAL/MILC, averaged by FLAG]

$$f_{B_s} = (228 \pm 8)\,\mathrm{MeV}$$

[Latest combination of LHCb and CMS results]
[Monday's talk by Francesco Dettori]

$$\mathrm{Br}(B_s \to \mu^+\mu^-) = (2.9 \pm 0.7) \times 10^{-9}$$

$$y_s = 0.08 \pm 0.01$$

Observables

B → Kμμ q^2 spectrum

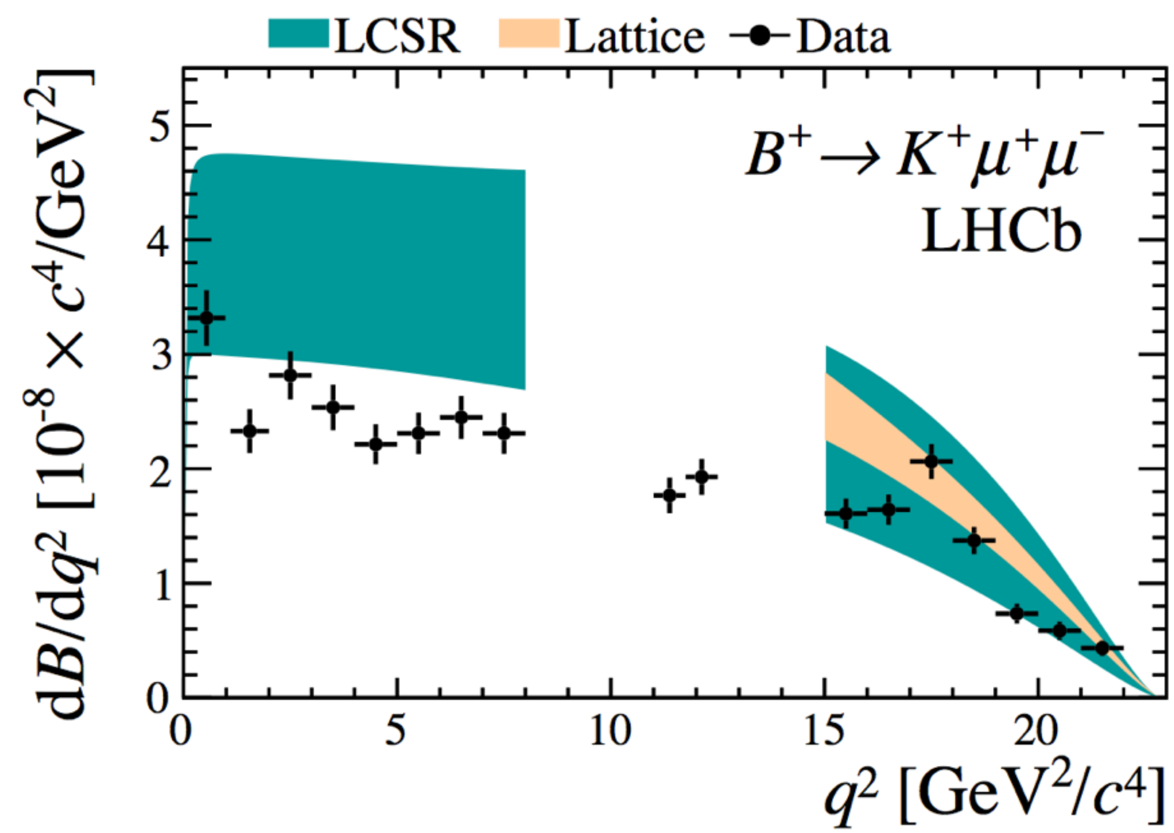
$$\frac{d\Gamma}{dq^2} = 2\left(a_\ell(q^2) + \frac{1}{3}c_\ell(q^2)\right)$$

$a_l(q^2)$ and $c_l(q^2)$ depend on sums of Wilson coefficients

$$C_9 + C_9'$$
$$C_{10} + C_{10}'$$
$$C_S + C_S'$$
$$C_P + C_P'$$

We employ unquenched lattice form factors

[Bouchard et al, Phys.Rev. D88]
[see talk by Stefan Meinel]



[LHCb 1403.8044]

Observables

$B \to K\mu\mu$ q^2 spectrum

$$\frac{d\Gamma}{dq^2} = 2\left(a_\ell(q^2) + \frac{1}{3}c_\ell(q^2)\right)$$

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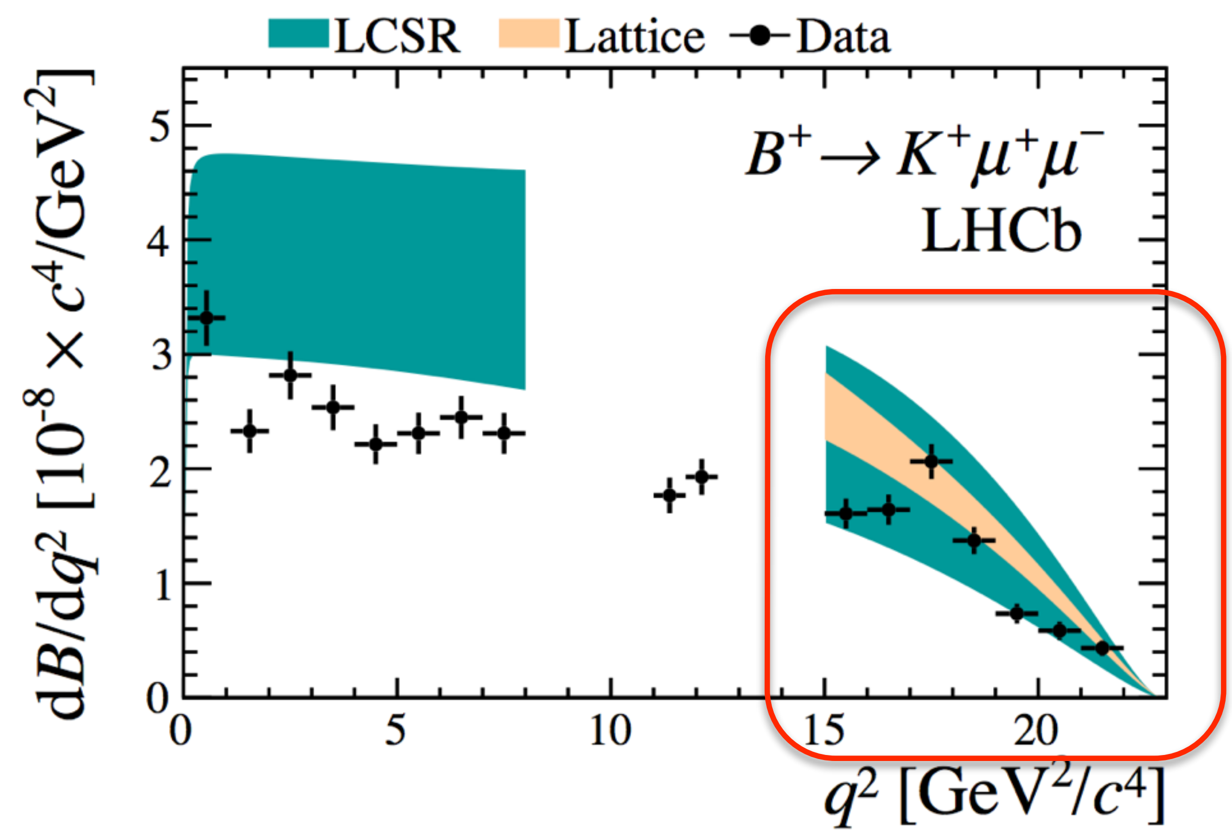


[LHCb 1403.8044]

High q^2 region: [15,22] GeV^2

$$\mathrm{Br}_{[15,22]\,\mathrm{GeV}^2} = (8.47 \pm 0.28 \pm 0.42) \times 10^{-8}$$

Expected to be larger in the SM

Observables

Inclusive $B \to X_s\mu\mu$ at low q^2

$$\int_{1\ \mathrm{GeV}^2}^{6\ \mathrm{GeV}^2} \frac{d\mathrm{Br}\left(B \to X_s \mu^+\mu^-\right)}{dq^2} dq^2 \Big|_{\mathrm{exp}} = 1.6(5) \times 10^{-6}$$

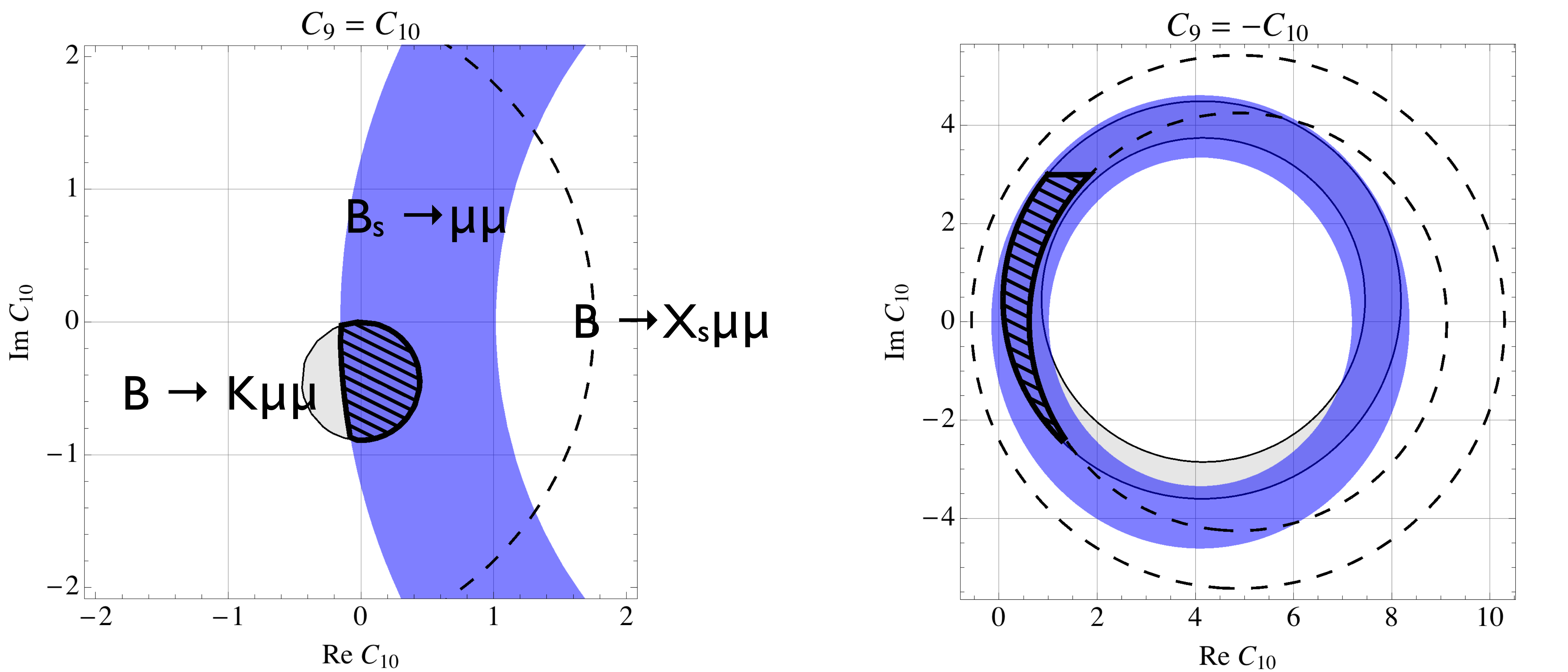
[T. Huber, T. Hurth, and E. Lunghi, NPB,802]
[A. Ali, E. Lunghi, C. Greub, and G. Hiller, PRD66]

B-factories average

Theoretical predictions rely on expressions from S. Fukae, C. Kim, and T. Yoshikawa, PRD 61

Parameter space of scalar LQ

Right chirality: 1σ regions of C_{10}



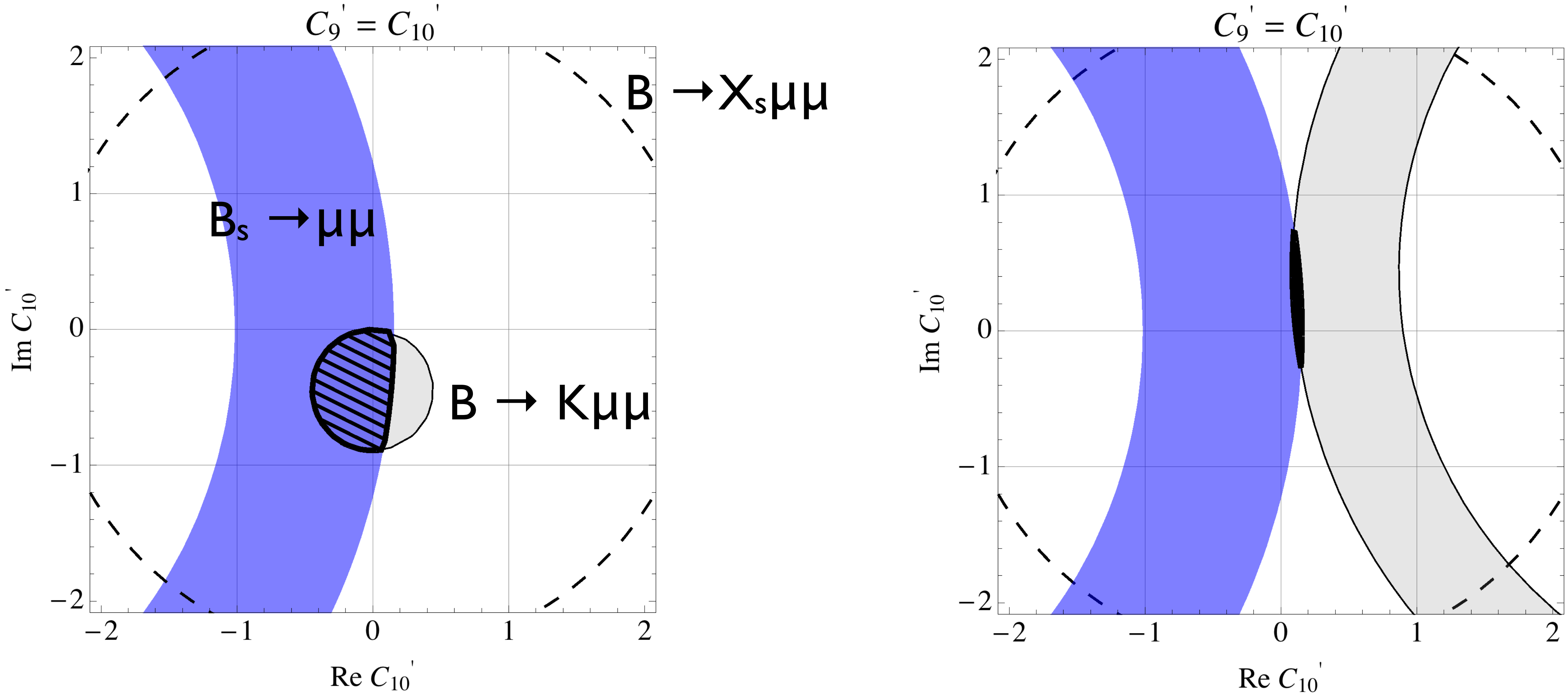
- $B_s \to \mu\mu$ constraint is not affected by the relative sign (C_9 is irrelevant)

- SM is not within the 1σ region due to $B \to K\mu\mu$

- Large cancellations possible in $B \to X_s\mu\mu$ and $B \to K\mu\mu$ with opposite C_9 and C_{10}

Parameter space of scalar LQ

Wrong chirality: 1σ regions of C_{10}'



- Only B → Kμμ is sensitive to sign between C_9' and C_{10}'

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Scalars

S	LQ	BNC	$\mathcal{O}_9$	$\mathcal{O}_{10}$	$\mathcal{O}_S$	$\mathcal{O}_P$	$\mathcal{O}'_9$	$\mathcal{O}'_{10}$	$\mathcal{O}'_S$	$\mathcal{O}'_P$	
0	$\Delta^{(7/6)}$	✓	C_{10}	C_{10}							$\sim 1-i$
	$\Delta^{(1/6)}$	✓					$-C'_{10}$	C'_{10}			$\sim i$
	$\Delta^{(4/3)}$						C'_{10}	C'_{10}			$\sim -1-i$
	$\Delta^{(1/3)}$		$-C_{10}$	C_{10}							$\sim 1\pm i$
	$V^{(3)}$	✓	$-C_{10}$	C_{10}							$\sim 1\pm i$

$$|(g_L)_{b\ell}(g_L)_{s\ell}|, |(g_R)_{b\ell}(g_R)_{s\ell}| \lesssim \text{few} \times 10^{-2}$$

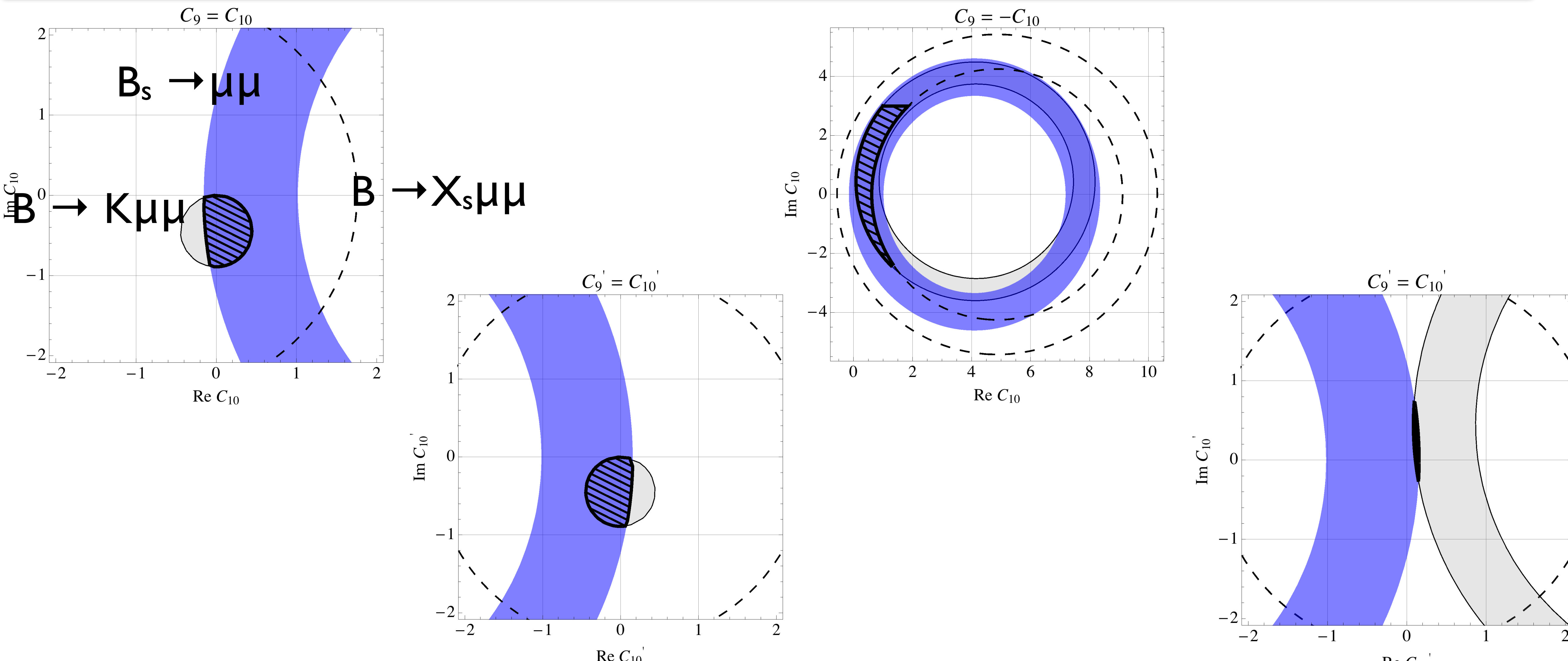
@ $m_\Delta = 1\,\mathrm{TeV/c^2}$

Comments

Leptonic and exclusive decays probe orthogonal combinations of Wilson coefficients.

Leptonic decay is a decent probe of (axial)vector operators.

Inclusive decay is becoming less competitive in constraining scalar LQ scenarios.



Comments

C_9 puzzle observed in $B \to K^*\mu\mu$ cannot be addressed by a single LQ

However, using a pair of scalar and vector we can modify C_9 while leaving everything else untouched.

S	LQ	BNC	$\mathcal{O}_9$	$\mathcal{O}_{10}$	$\mathcal{O}_S$	$\mathcal{O}_P$	$\mathcal{O}'_9$	$\mathcal{O}'_{10}$	$\mathcal{O}'_S$	$\mathcal{O}'_P$
0	$\Delta^{(7/6)}$	✓	C_{10}	C_{10}						
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0	$\Delta^{(4/3)}$						C'_{10}	C'_{10}		
0	$\Delta^{(1/3)}$		$-C_{10}$	C_{10}						
1	$V^{(3)}$	✓	$-C_{10}$	C_{10}						
1	$V^{(1)}$		$-C_{10}$	C_{10}	C_S	$-C_S$	C'_{10}	C'_{10}	C'_S	C'_S
1	$V^{(2)}$		C_{10}	C_{10}	C_S	C_S	$-C'_{10}$	C'_{10}	C'_S	$-C'_S$

Conclusions

Leptoquarks are a viable framework, can be embedded in realistic GUT models.

In general, there is no objective objection to having light leptoquarks (IF they conserve B number).

$(b\underline{s})(\underline{\mu}\mu)$ can be studied independently of UV completion.

Interplay with other flavour constraints, e.g., scalar (3,2,7/6) scalar can explain the observed $B \to D^{(*)}\tau\nu$ branching fractions.

Interplay with LEP precision physics, direct production at the LHC.
☞ talk by Svjetlana Fajfer

Thank you for your attention!